

# **Hydraulic Hybrids**

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## **Cost-Effective Clean Urban Vehicles**



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# What is a Hybrid?

- A hybrid drivetrain is simply another kind of transmission
  - Manual, automatic or hybrid
  - It is one that can recover, store and reuse power either electrically or hydraulically.
- A hybrid vehicle, in addition to its main engine, has a drive train that contains:
  - An energy storage system
  - A special drive system to convert the stored energy to motive power

## Hydraulic Hybrids

- Store energy in hydraulic accumulators
- Use hydraulic pump-motors

## Electric Hybrids

- Store energy in batteries and/or ultra-capacitors
- Use electric generator-motors

# Why Hydraulic Hybrids?

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- Highest possible fuel economy**
  - Lowest incremental cost**
    - **Shortest payback to owner**
    - **Highest lifetime-savings**
  - Ultra-low emissions**
  - Enables unique high efficiency engines**
  - Greater reductions in greenhouse gases**
  - Greater reductions in imported oil**
- Vehicle technologies that deliver real-world results cost-effectively!*

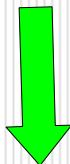
# Ways to Increase Average Vehicle Efficiency....

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## 1. Capture and re-use energy lost to friction braking

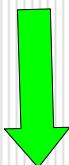
- ✓ Regenerative Braking

**Cost-Effective  
Hybrids**



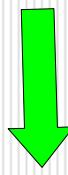
## 2. Improve average efficiency of the engine / drivetrain

- ✓ Shutoff engine at idle
- ✓ Operate engine at "sweet" spot
- ✓ Shutoff engine at all times when not needed



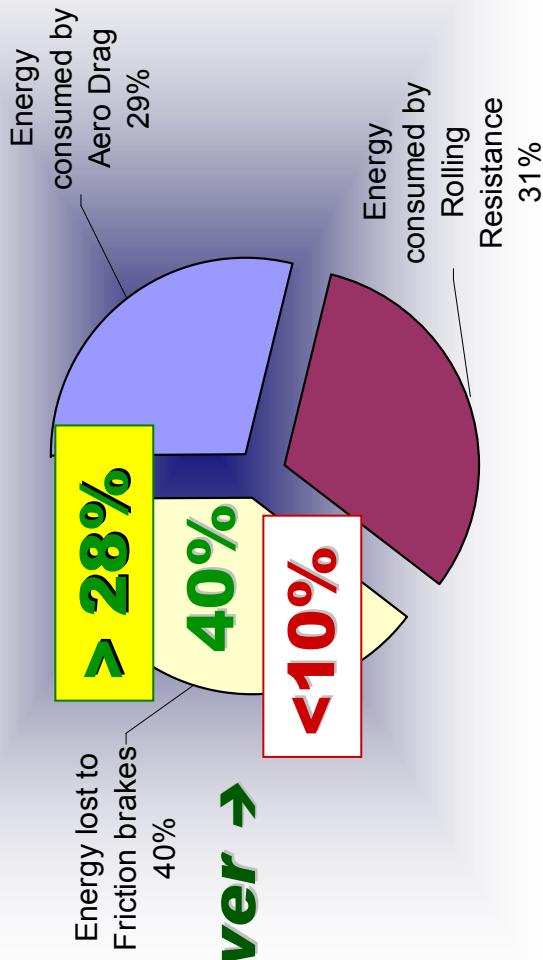
## 3. Reduce the energy needs at the wheels

- ✓ Reduce Aerodynamic Drag
- ✓ Reduce Rolling Resistance



# Regenerative Braking

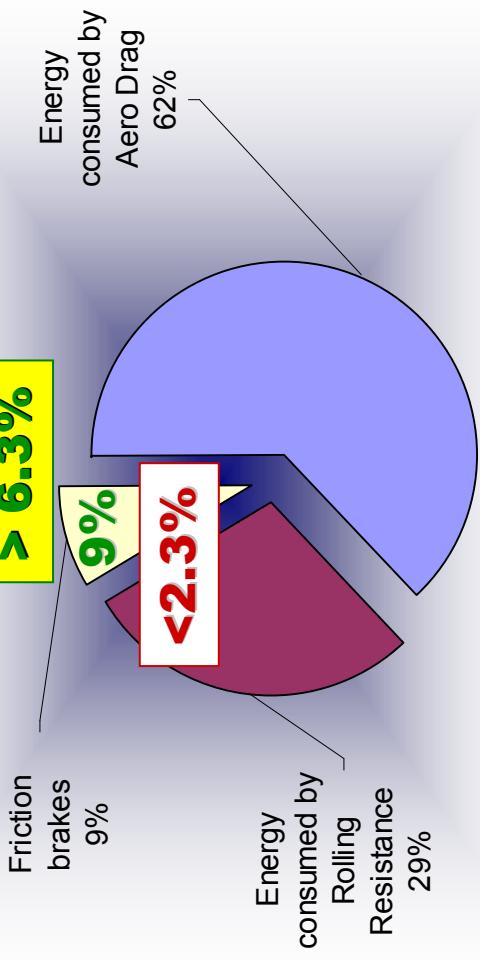
EPA City Cycle Energy Delivered to the Wheels  
(Baseline- 20000 lbs, vt365)



**Hybrids try to recover → this energy**

**Where Does the Energy at the Wheels Go?**

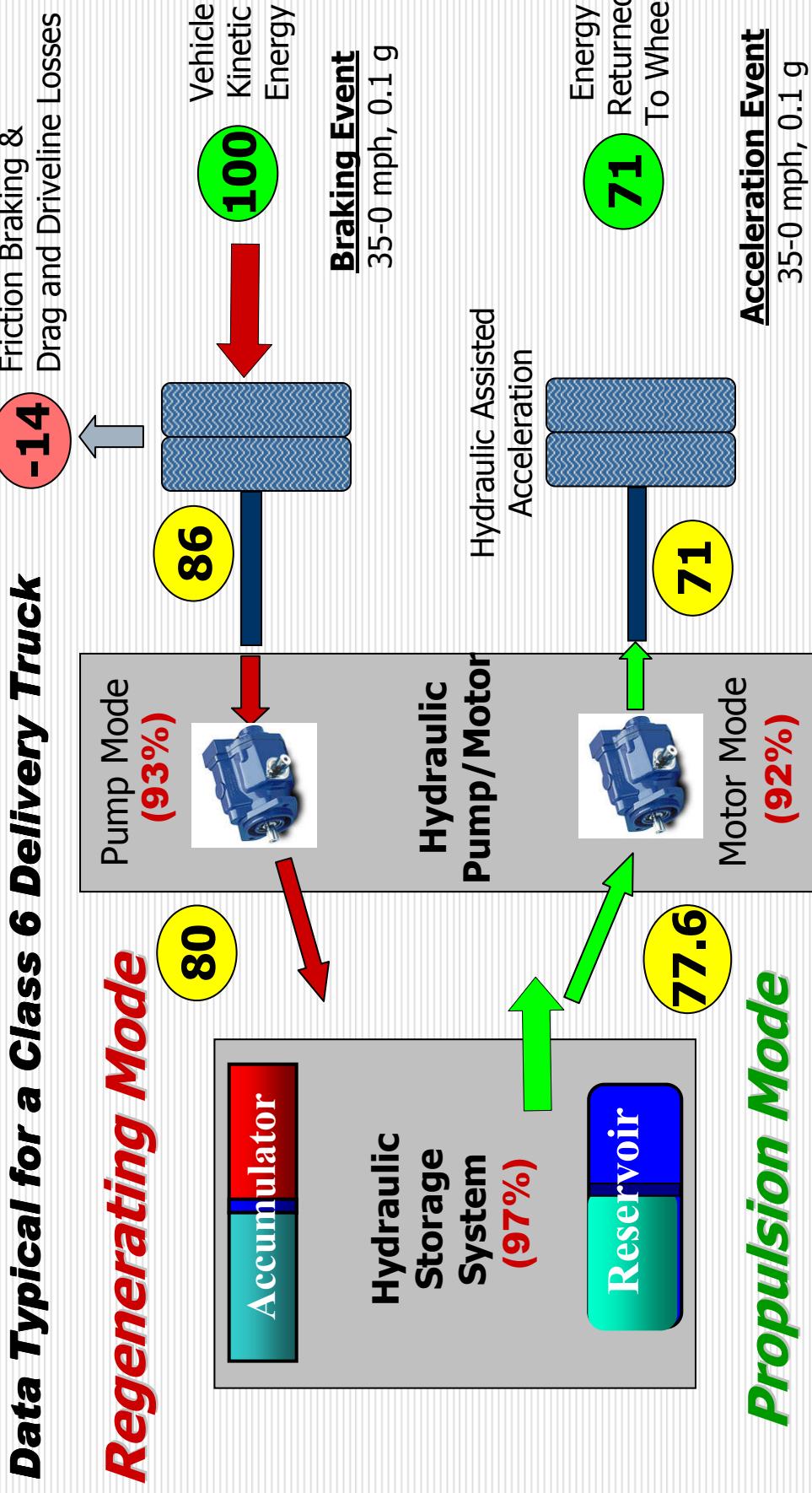
EPA Highway Cycle Energy Delivered to the Wheels  
(Baseline- 20000, vt365)



**Electric Hybrids <25%**

**Hydraulic Hybrids >70%**

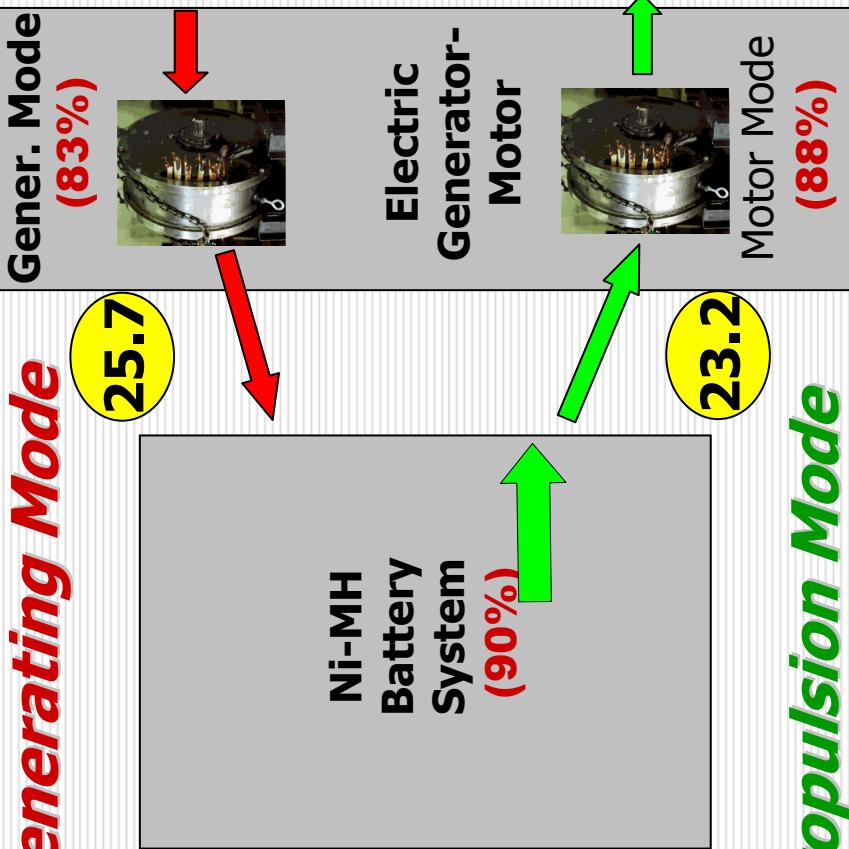
# Efficiencies While Braking/Accelerating Hydraulically



# Efficiencies While Braking/Accelerating Electrically

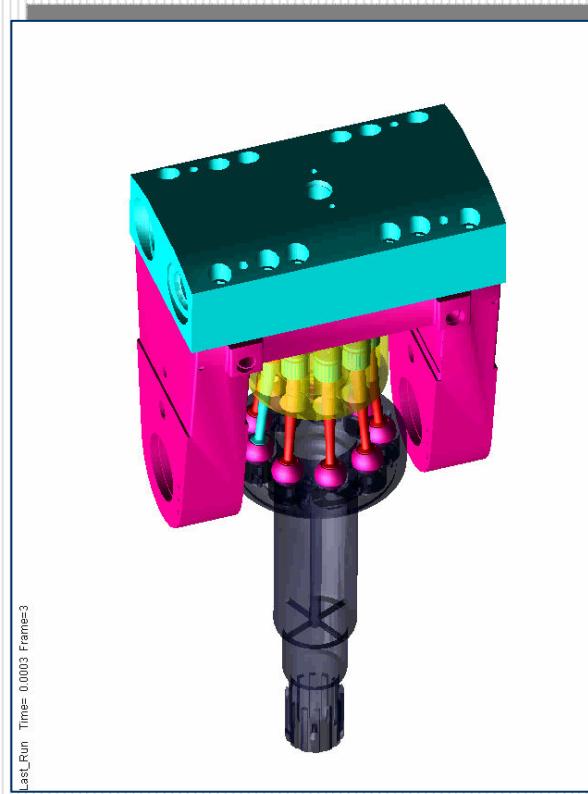
## ***Data Typical for a Class 6 Delivery Truck***

### ***Regenerating Mode***



# Hydraulic Components

## Integrated Bent-Axis Hydraulic Pump- Motors



## Hydraulic Hybrid Accumulators



**1. Charge/discharge cycle efficiency:** **95-99%**

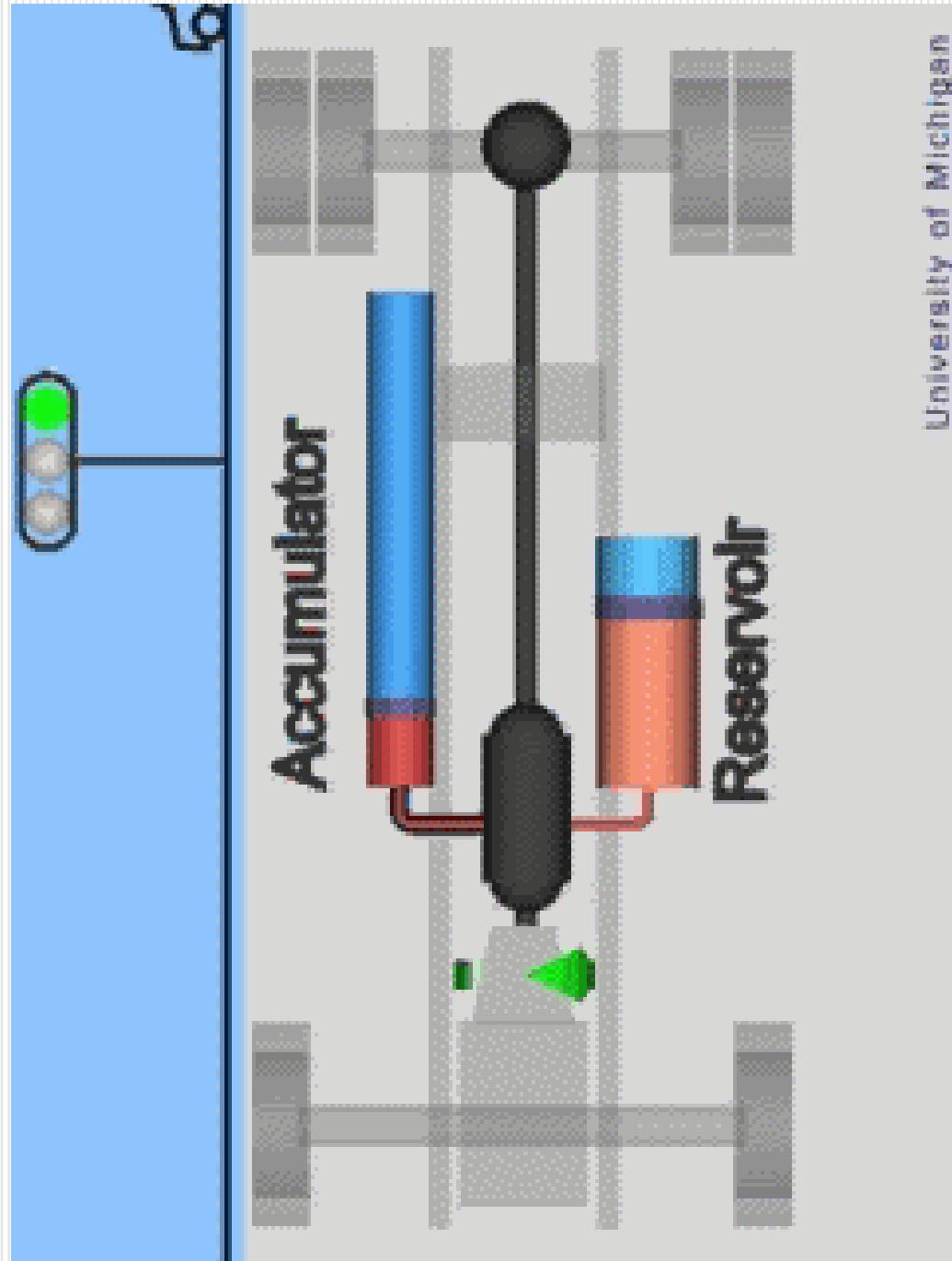
**2. Specific power:** High pressure accumulator (with oil that transfers the power/energy) can deliver very high specific power in excess of **3 kw/kg**

**3. Energy density:** **>50 kw-sec/gal**

**4. Specific energy:** **~8 kw-sec/kg**

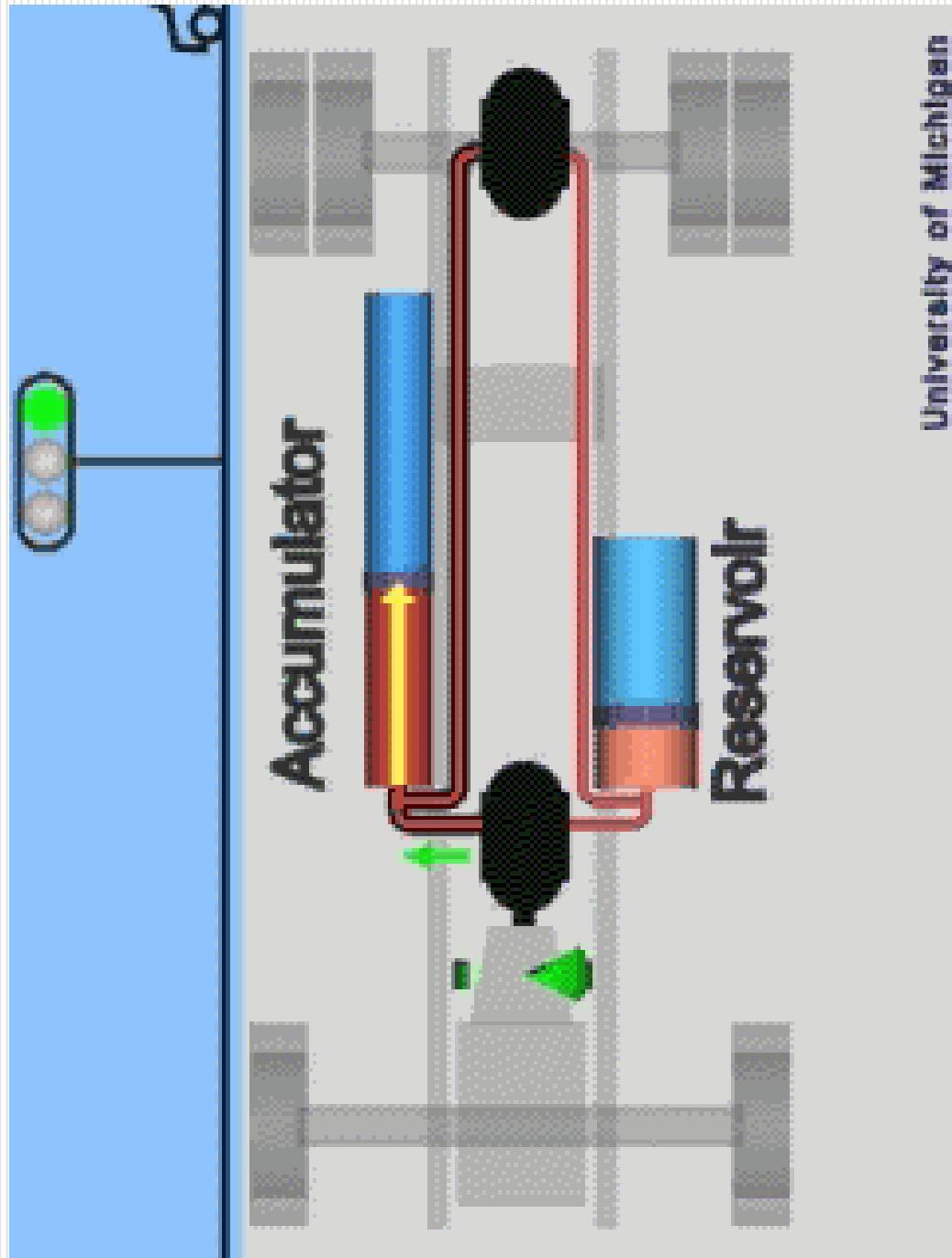
**5. Specific costs:** **\$10/kg**

# Parallel Hydraulic Hybrid Operation



*Illustration courtesy of Automotive Research Center – University of Michigan*

# Series Hydraulic Hybrid Operation



*Illustration courtesy of Automotive Research Center – University of Michigan*

# Hydraulic Hybrids Efficiency

## Parallel versus Series

Series hybrid designs enable the next step in hybrid design – big opportunities for:

- More efficient engine operation, and
- Unique, even more cost-effective engines
- Higher fuel economy with less incremental cost

Hybrid Configurations	Vehicle Fuel Economy Improvement
Mild Hybrid (parallel, launch assist with conventional engines)	<b>20-40%</b>
Full Hybrid (series) with conventional engines	<b>60-80%</b>
<b>Future Full</b> Hybrid (series) with advanced engines, improved aerodynamics, and tires	<b>100-120%</b>

# This is Just the Beginning... More FE Improvements Coming!

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## ***Advanced High Efficiency Engines Enabled by Full Series Hybrids***

### ***HCCI - Homogenous Charge Compression Ignition***

- Diesel efficiency levels from gasoline (Tier2 bin 2)

### ***Free Piston Engine***

- Hydraulic power directly from engine – no crank

### ***Complete Variable Displacement Engine***

- Twin Crank engine to maximize engine efficiency yet have peak power available on-demand

### ***Thermal Energy Recovery***

- Recover energy from the waste exhaust heat

## **Types of Questions You Need to Ask Yourself To “Spec-out” Fleet Hybrids**

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- What level of emission reduction do you want?
- What fuel economy gain do you desire? (mpg)
- Does your fleet have a duty-cycle that will bring suitable fuel economy gains?
- How much weight gain can you tolerate?
- What level of redundancy do you need?
- Do you need on-board electricity?
- How long can you wait for the system to pay for itself?

# Types of Questions to Ask Hybrid Manufacturers

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- What is your “round-trip” wheel-to-wheel regeneration efficiency?
- Do you shut engine off at idle?
- Over what drive cycle was the vehicle tested?
- What is engine efficiency over entire drive cycle?
- What percent is the engine off over drive cycle?

# Challenges to Proliferation of Hybrids in Commercial Vehicles

Assessment of Current Systems	Future Potential Targets
1. Fuel Economy Increase	100%+
2. Incremental Cost	10-15% of base vehicle (high volumes)
3. Payback Period	2-3 years

**EPA is focusing its efforts to achieve the targets using full series "hydraulic" hybrid designs**

# Growing Interest In Using Hydraulic Hybrids

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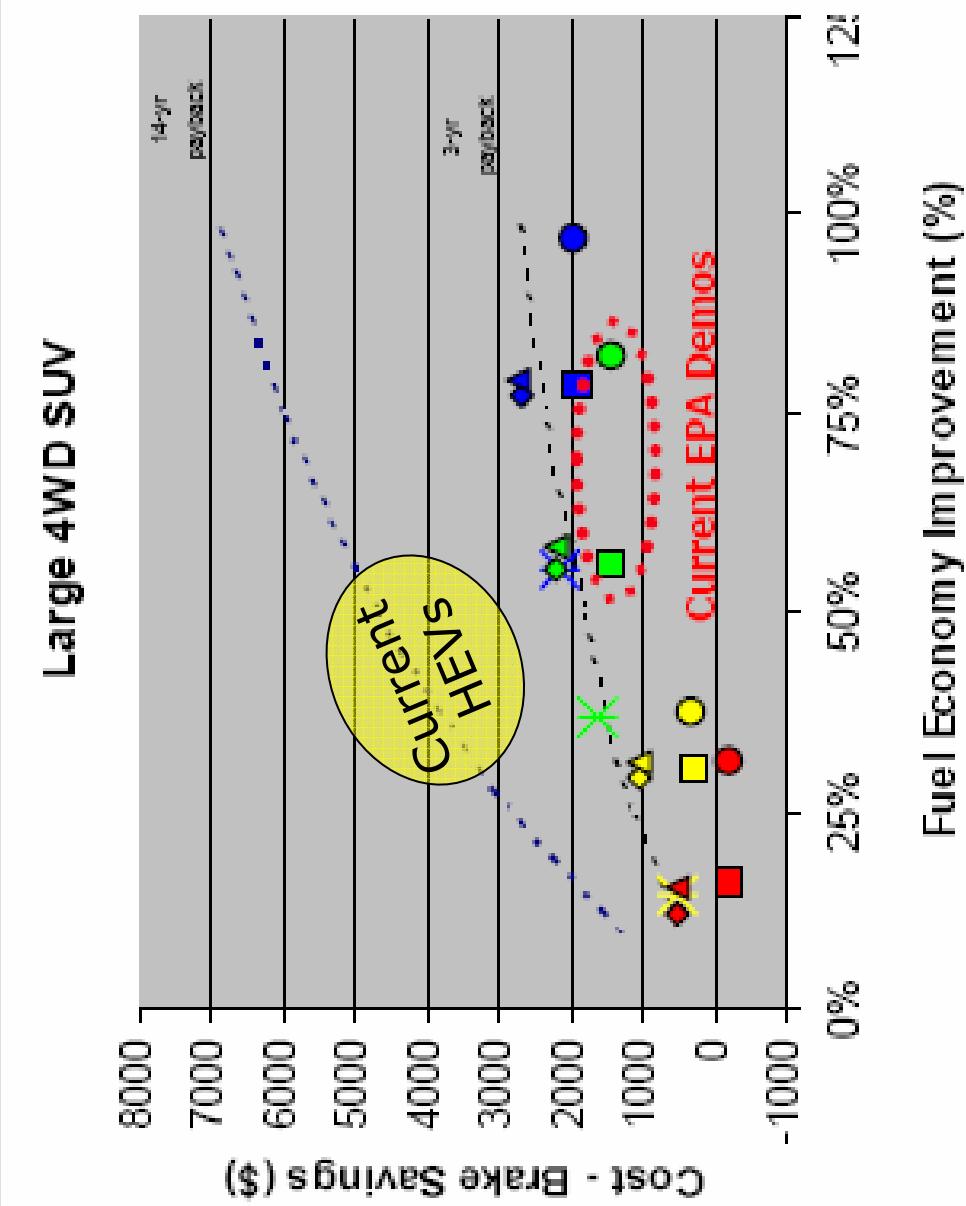
## ■ Interested Groups

- ✓ **Users/Fleets**– Army, refuse industry, Hybrid Truck User's Forum's (HTUF) Hybrid Parcel Delivery WG is now pursuing hydraulic hybrids
- ✓ **Manufacturer/Suppliers**– International, Eaton, Parker-Hannifin, Dana/Permodrive, HybraDrive, Hydraulic Innovations
- ✓ **Hydraulic Hybrid Working Group** – formed through NextEnergy; focusing on industry issues associated with commercializing hydraulic hybrids –  
[www.nextenergy.org/industrygroups](http://www.nextenergy.org/industrygroups)

## ■ Publications

- ✓ **2004 EPA Technical Report** – focus on the efficiency, cost and payback of hydraulic hybrid technology  
[www.epa.gov/otaq/technology/#tech](http://www.epa.gov/otaq/technology/#tech)
- ✓ **2005 SAE Paper** - Hydraulic versus Electric Hybrid Fuel Economy – Ricardo paper (SAE# 2005-01-1164)

# Comparison of SUV Technologies... Consumer Payback



**Progress Report on Clean and Efficient Automotive Technologies Under Development at EPA - January 2004**  
[www.epa.gov/otaq/technology](http://www.epa.gov/otaq/technology)

# EPA's Full Series Hydraulic Hybrid SUV Demonstration Vehicle

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## Communicates a Vision of "Production Potential" for SUV's and Light Trucks

- Diesel & 4-WD hydraulic hybrid ("HH") shows 85% fuel economy improvement & better acceleration
- \$2200 incremental cost add for diesel engine and hydraulic hybrid technology means excellent 1-2 year payback for consumer (assumes high volume)



# EPA's Full Series Hydraulic Hybrid Urban Delivery Vehicle

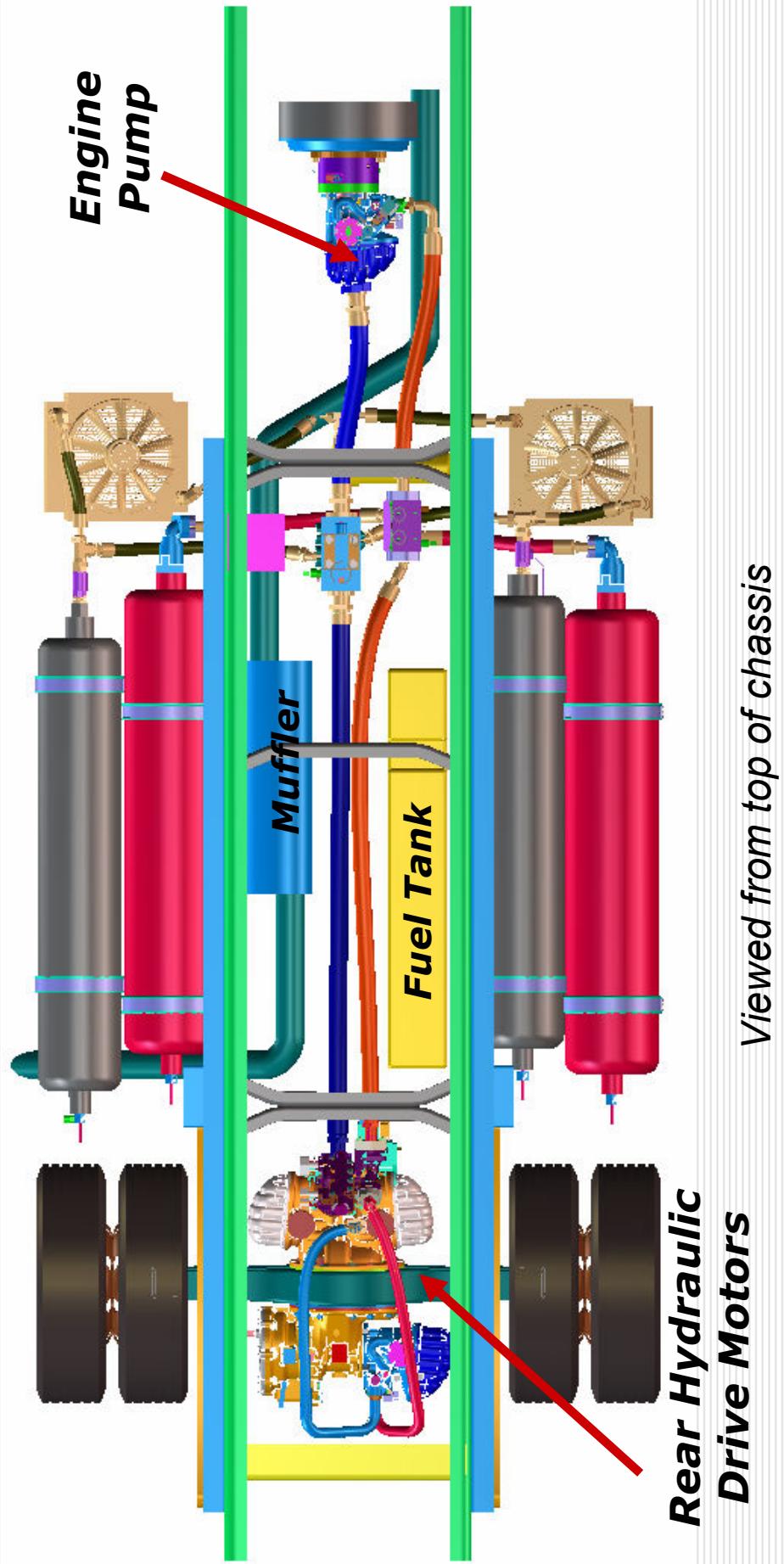
## Hydraulic Hybrid UPS Package Car Demo Creates Visibility With "Real World" Experience



- 60-70% mpg improvement in city driving
- 2-3 year payback has attracts attention from fleets
- Potential for net Lifetime savings over \$20,000
- Demonstration to accelerate technology transfer to industry & familiarity with technology
- Partners (UPS, Eaton, International Truck, U.S. Army)

New York Times (Feb 10, 2005) - "The Environmental Protection Agency and the United Parcel Service announce a test project today demonstrating a new type of transmission that could save energy and reduce pollution."

# EPA's Layout Configuration for Hydraulic Hybrid UPS Truck



*Viewed from top of chassis*